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International Baccalaureate
Baccalauréat International
Bachillerato Internacional

CHEMISTRY
HIGHER LEVEL
PAPER 2

Thursday 11 November 2010 (afternoon)

2 hours 15 minutes

Candidate session number

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INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all of Section A in the spaces provided.
- Section B: answer two questions from Section B. Write your answers on answer sheets. Write your session number on each answer sheet, and attach them to this examination paper and your cover sheet using the tag provided.
- At the end of the examination, indicate the numbers of the questions answered in the candidate box on your cover sheet and indicate the number of sheets used in the appropriate box on your cover sheet.

SECTION A

*Answer **all** the questions in the spaces provided.*

1. The data below are from an experiment to measure the enthalpy change for the reaction of aqueous copper(II) sulfate, $CuSO_4(aq)$ and zinc, Zn(s).

$$Cu^{2+}(aq) + Zn(s) \rightarrow Cu(s) + Zn^{2+}(aq)$$

50.0 cm^3 of 1.00 mol dm^{-3} copper(II) sulfate solution was placed in a polystyrene cup and zinc powder was added after 100 seconds. The temperature-time data was taken from a data-logging software program. The table shows the initial 23 readings.

	A	B	C	D	E	F	G	H
1	**time / s**	**Temperature / °C**						
2	0.0	24.8						
3	1.0	24.8						
4	2.0	24.8						
5	3.0	24.8						
6	4.0	24.8						
7	5.0	24.8						
8	6.0	24.8						
9	7.0	24.8						
10	8.0	24.8						
11	9.0	24.8						
12	10.0	24.8						
13	11.0	24.8						
14	12.0	24.8						
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18	16.0	24.8						
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20	18.0	24.8						
21	19.0	24.8						
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23	21.0	24.8						
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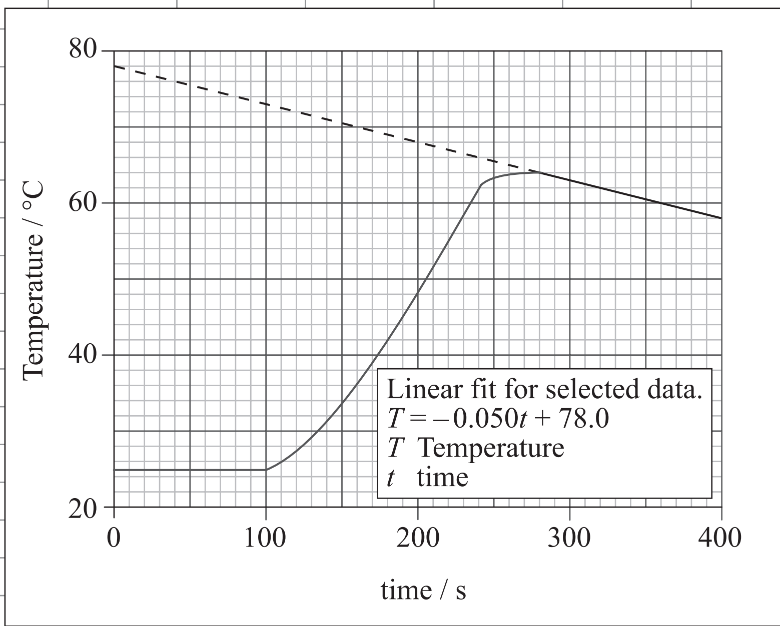

A straight line has been drawn through some of the data points. The equation for this line is given by the data logging software as

$$T = -0.050t + 78.0$$

where T is the Temperature at time t.

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(Question 1 continued)

(a) The heat produced by the reaction can be calculated from the temperature change, ΔT, using the expression below.

$$\text{Heat change} = \text{Volume of } CuSO_4(aq) \times \text{Specific heat capacity of } H_2O \times \Delta T$$

Describe **two** assumptions made in using this expression to calculate heat changes. *[2]*

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(b) (i) Use the data presented by the data logging software to deduce the temperature change, ΔT, which would have occurred if the reaction had taken place instantaneously with no heat loss. *[2]*

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(ii) Calculate the heat, in kJ, produced during the reaction using the expression given in part (a). *[1]*

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(c) The colour of the solution changed from blue to colourless. Deduce the amount, in moles, of zinc which reacted in the polystyrene cup. *[1]*

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(d) Calculate the enthalpy change, in $kJ\,mol^{-1}$, for this reaction. *[1]*

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(Question 1 continued)

(e) An experiment was designed to investigate how the enthalpy change for a displacement reaction relates to standard electrode potentials. The standard electrode potentials of some half reactions, $M^{n+}(aq) + ne^{-} \rightleftharpoons M(s)$, are listed in Table 14 of the Data Booklet. The following metals were available: copper, iron, magnesium, silver and zinc. Excess amounts of each metal were added to $1.00\ mol\,dm^{-3}$ copper(II) sulfate solution. The temperature change was measured and the enthalpy change calculated.

(i) Suggest a possible hypothesis for the relationship between the enthalpy change that occurs when the metal, M, is added to copper(II) sulfate (aq) and the standard electrode potential for the half reaction $M^{n+}(aq) + ne^{-} \rightleftharpoons M(s)$. *[1]*

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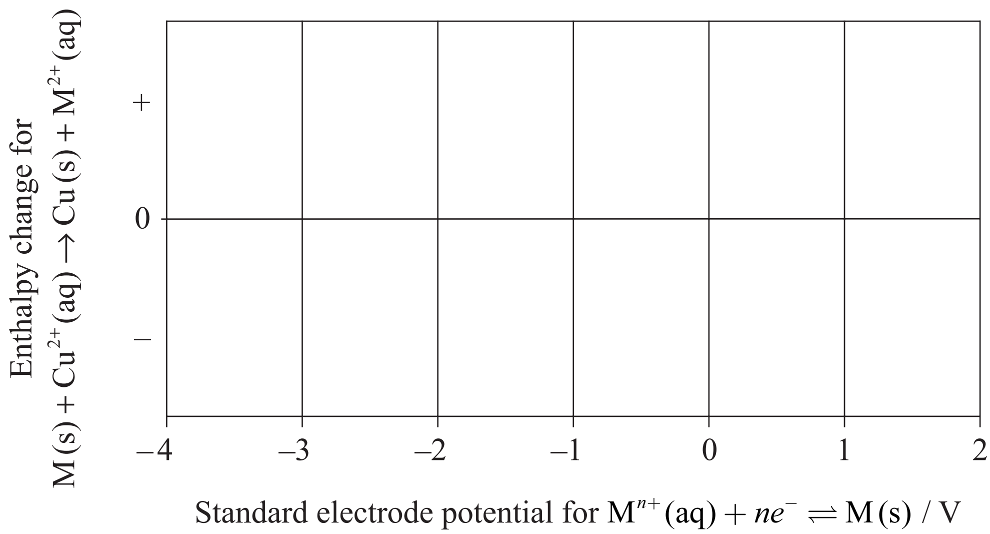
(ii) Sketch a graph on the diagram below to illustrate your hypothesis. *[2]*



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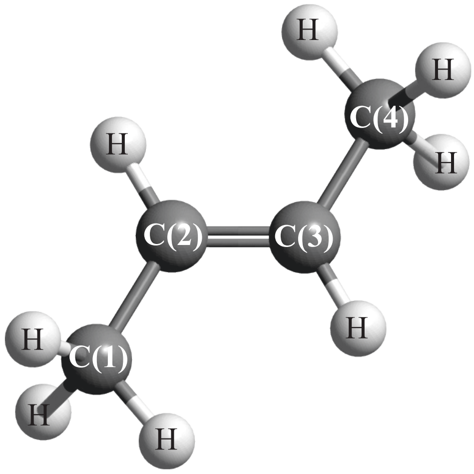
2. (a) But-2-ene is a straight-chain alkene with formula C_4H_8. The molecule contains both σ and π bonds.



(i) Explain the formation of the π bond. *[2]*

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(ii) For each of the carbon atoms, C(1) and C(2), identify the type of hybridization shown. *[1]*

C(1): . . . .

C(2): . . . .

(b) But-2-ene shows geometrical isomerism. Draw the structural formula and state the name of the other geometrical isomer. *[2]*

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(Question 2 continued)

(c) Identify the structural formula of an isomer of but-2-ene which does not decolourize bromine water, $Br_2(aq)$. *[1]*

(d) The polymerization of the alkenes is one of the most significant reactions of the twentieth century.

(i) Outline **two** reasons why the polymers of the alkenes are of economic importance. *[2]*

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(ii) State the type of polymerization reaction shown by the alkene in part (a). *[1]*

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(iii) Deduce the structure of the resulting polymer showing **three** repeating units. *[1]*

(iv) Explain why monomers are often gases or volatile liquids, but polymers are solids. *[2]*

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3. Iron has three main naturally occurring isotopes which can be investigated using a mass spectrometer.

(a) The first stage in the operation of the mass spectrometer is vaporization. The iron is then ionized.

(i) Explain why the iron is ionized. *[2]*

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(ii) Explain why a very low pressure is maintained inside the mass spectrometer. *[1]*

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(b) A sample of iron has the following isotopic composition by mass.

Isotope	^{54}Fe	^{56}Fe	^{57}Fe
Relative abundance / %	5.95	91.88	2.17

Calculate the relative atomic mass of iron based on this data, giving your answer to **two decimal places.** *[2]*

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(Question 3 continued)

(c) Describe the bonding in iron and explain the electrical conductivity and malleability of the metal. *[4]*

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(d) State the full electronic configurations of a Cu atom and a Cu^{+} ion. *[2]*

Cu: . . . .

Cu^{+}: . . . .

(e) Explain the origin of colour in transition metal complexes and use your explanation to suggest why copper(II) sulfate, $CuSO_4(aq)$, is blue, but zinc sulfate, $ZnSO_4(aq)$, is colourless. *[4]*

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(f) $Cu^{2+}(aq)$ reacts with ammonia to form the complex ion $[Cu(NH_3)_4]^{2+}$. Explain this reaction in terms of an acid-base theory, and outline how the bond is formed between Cu^{2+} and NH_3. *[3]*

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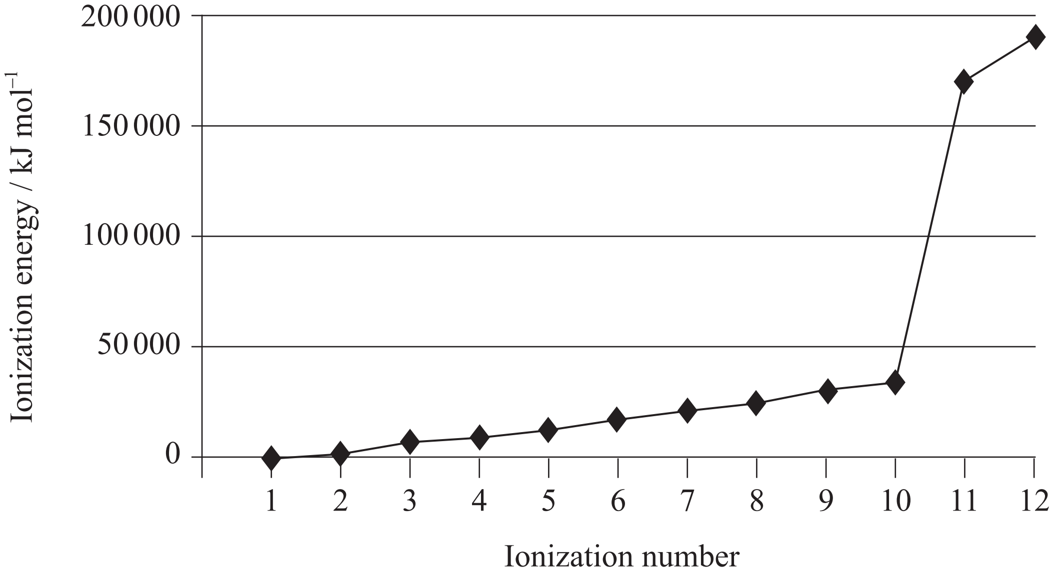
SECTION B

*Answer **two** questions. Write your answers on the answer sheets provided. Write your session number on each answer sheet, and attach them to this examination paper and your cover sheet using the tag provided.*

4. Magnesium is the eighth most abundant element in the earth's crust. The successive ionization energies of the element are shown below.



(a) (i) Define the term *first ionization energy* and state the equation for the first ionization of magnesium. *[3]*

(ii) Explain the general increase in successive ionization energies of the element. *[2]*

(iii) Explain the large increase between the tenth and eleventh ionization energies. *[3]*

(b) Magnesium can be produced from the electrolysis of molten magnesium chloride, $MgCl_2$.

(i) Explain how molten magnesium chloride conducts an electric current. *[2]*

(ii) Identify the electrode where oxidation occurs during electrolysis of molten magnesium chloride and state an equation for the half-reaction. *[2]*

(iii) Explain why magnesium is not formed during the electrolysis of aqueous magnesium chloride solution. *[1]*

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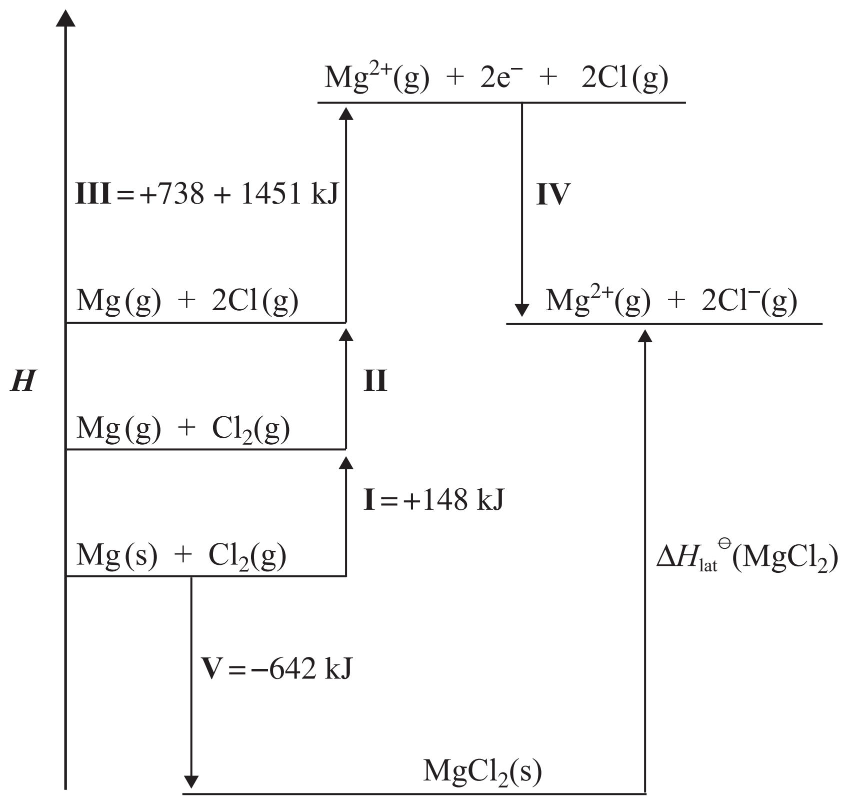
(Question 4 continued)

(c) The lattice enthalpy of magnesium chloride can be calculated from the Born-Haber cycle shown below.



(i) Identify the enthalpy changes labelled by **I** and **V** in the cycle. *[2]*

(ii) Use the ionization energies given in the cycle above and further data from the Data Booklet to calculate a value for the lattice enthalpy of magnesium chloride. *[4]*

(iii) The theoretically calculated value for the lattice enthalpy of magnesium chloride is +2326 kJ. Explain the difference between the theoretically calculated value and the experimental value. *[2]*

(iv) The experimental lattice enthalpy of magnesium oxide is given in Table 13 of the Data Booklet. Explain why magnesium oxide has a higher lattice enthalpy than magnesium chloride. *[2]*

(d) (i) State whether aqueous solutions of magnesium oxide and magnesium chloride are acidic, alkaline or neutral. *[1]*

(ii) State an equation for the reaction between magnesium oxide and water. *[1]*

5. Consider the following sequence of reactions.

$$RCH_3 \xrightarrow{\textit{reaction 1}} RCH_2Br \xrightarrow{\textit{reaction 2}} RCH_2OH$$

RCH_3 is an unknown alkane in which R represents an alkyl group.

(a) The alkane contains 82.6 % by mass of carbon. Determine its empirical formula, showing your working. *[3]*

(b) A 1.00 g gaseous sample of the alkane has a volume of 385 cm^3 at standard temperature and pressure. Deduce its molecular formula. *[2]*

(c) State the reagent and conditions needed for *reaction 1*. *[2]*

(d) *Reaction 1* involves a free-radical mechanism. Describe the stepwise mechanism, by giving equations to represent the initiation, propagation and termination steps. *[4]*

(e) The mechanism in *reaction 2* is described as S_N2. Explain the mechanism of this reaction using curly arrows to show the movement of electron pairs, and draw the structure of the transition state. *[3]*

(f) There are four structural isomers with the molecular formula C_4H_9Br. One of these structural isomers exists as two optical isomers. Draw diagrams to represent the three-dimensional structures of the two optical isomers. *[2]*

(g) All the isomers can by hydrolysed with aqueous sodium hydroxide solution. When the reaction of one of these isomers, **X**, was investigated the following kinetic data were obtained.

Experiment	**Initial [X] / mol dm^{-3}**	**Initial [OH$^-$] / mol dm^{-3}**	**Initial rate of reaction / mol dm^{-3} min^{-1}**
1	2.0×10^{-2}	2.0×10^{-2}	4.0×10^{-3}
2	2.0×10^{-2}	4.0×10^{-2}	4.0×10^{-3}
3	4.0×10^{-2}	4.0×10^{-2}	8.0×10^{-3}

(i) Deduce the rate expression for the reaction. *[3]*

(ii) Determine the value of the rate constant for the reaction and state its units. *[2]*

(iii) State the name of isomer **X** and explain your choice. *[2]*

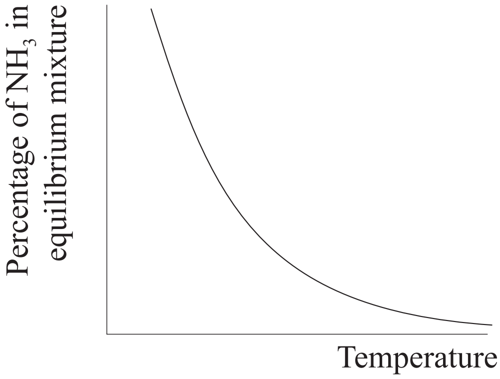
(iv) State equations for the steps that take place in the mechanism of this reaction and state which of the steps is slow and which is fast. *[2]*

6. The Haber process enables the large-scale production of ammonia needed to make fertilizers.

(a) The equation for the Haber process is given below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The percentage of ammonia in the equilibrium mixture varies with temperature.



(i) Use the graph to deduce whether the forward reaction is exothermic or endothermic and explain your choice. *[2]*

(ii) State and explain the effect of increasing the pressure on the yield of ammonia. *[2]*

(iii) Deduce the equilibrium constant expression, K_c, for the reaction. *[1]*

(iv) A mixture of 1.00 mol N_2 and 3.00 mol H_2 was placed in a 1.0 dm^3 flask at 400 °C. When the system was allowed to reach equilibrium, the concentration of NH_3 was found to be 0.062 $mol\,dm^{-3}$. Determine the equilibrium constant, K_c, of the reaction at this temperature. *[3]*

(v) Iron is used as a catalyst in the Haber process. State the effect of a catalyst on the value of K_c. *[1]*

(b) Ammonia can be converted into nitric acid, $HNO_3(aq)$, and hydrocyanic acid, $HCN(aq)$. The pK_a of hydrocyanic acid is 9.21.

(i) Distinguish between the terms *strong* and *weak acid* and state the equations used to show the dissociation of each acid in aqueous solution. *[3]*

(ii) Deduce the expression for the ionization constant, K_a, of hydrocyanic acid and calculate its value from the pK_a value given. *[2]*

(iii) Use your answer from part (b) (ii) to calculate the $[H^+]$ and the pH of an aqueous solution of hydrocyanic acid of concentration 0.108 $mol\,dm^{-3}$. State **one** assumption made in arriving at your answer. *[4]*

(This question continues on the following page)

(Question 6 continued)

(c) A small piece of magnesium ribbon is added to solutions of nitric and hydrocyanic acid of the same concentration at the same temperature. Describe **two** observations that would allow you to distinguish between the two acids. *[2]*

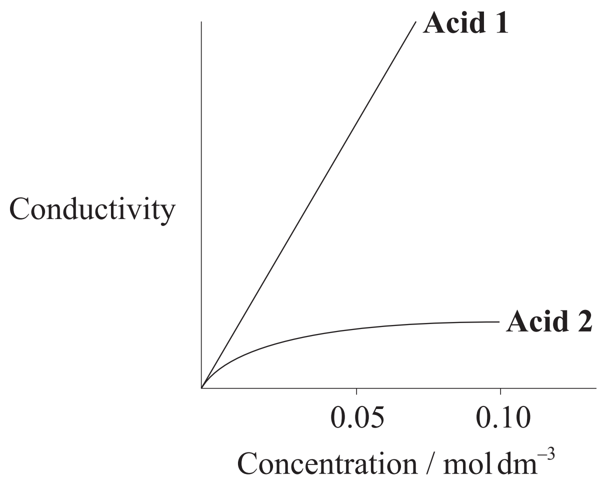
(d) A student decided to investigate the reactions of the two acids with separate samples of $0.20\ mol\,dm^{-3}$ sodium hydroxide solution.

(i) Calculate the volume of the sodium hydroxide solution required to react exactly with a $15.0\ cm^3$ solution of $0.10\ mol\,dm^{-3}$ nitric acid. *[1]*

(ii) The following hypothesis was suggested by the student: "Since hydrocyanic acid is a weak acid it will react with a smaller volume of the $0.20\ mol\,dm^{-3}$ sodium hydroxide solution." Comment on whether or not this is a valid hypothesis. *[1]*

(iii) Use Table 16 of the Data Booklet to identify a suitable indicator for the titration of sodium hydroxide and hydrocyanic acid. *[1]*

(e) The graph below shows how the conductivity of the two acids changes with concentration.



Identify **Acid 1** and explain your choice. *[2]*

7. Hydrazine, N_2H_4, is a valuable rocket fuel.

(a) (i) Draw the Lewis (electron dot) structure for N_2H_4 showing all valence electrons. *[1]*

(ii) State and explain the H–N–H bond angle in hydrazine. *[3]*

(b) Hydrazine and ethene, C_2H_4, are hydrides of adjacent elements in the periodic table. The boiling point of hydrazine is much higher than that of ethene. Explain this difference in terms of the intermolecular forces in each compound. *[2]*

(c) The equation for the reaction between hydrazine and oxygen is given below.

$$N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2H_2O(l)$$

(i) The enthalpy change of formation, $\Delta H_f^{\ominus}$, of liquid hydrazine is $50.6\ \text{kJ}\,\text{mol}^{-1}$. Use this value, together with data from Table 12 of the Data Booklet, to calculate the enthalpy change for this reaction. *[3]*

(ii) Use the bond enthalpy values from Table 10 of the Data Booklet to determine the enthalpy change for this reaction. *[3]*

(iii) Identify the calculation that produces the most accurate value for the enthalpy change for the reaction given and explain your choice. *[3]*

(iv) Calculate $\Delta S^{\ominus}$ for the reaction using the data below and comment on its magnitude. *[3]*

Substance	$\mathbf{S^{\ominus}\ /\ J\,K^{-1}\,mol^{-1}}$
$O_2(g)$	205
$N_2(g)$	191
$H_2O(l)$	69.9
$N_2H_4(l)$	121

(v) Calculate $\Delta G^{\ominus}$ for the reaction at 298 K. *[2]*

(vi) Predict, giving a reason, the spontaneity of the reaction above at both high and low temperatures. *[2]*

(This question continues on the following page)

(Question 7 continued)

(d) The reaction between $N_2H_4(aq)$ and $HCl(aq)$ can be represented by the following equation.

$$N_2H_4(aq) + 2HCl(aq) \rightarrow N_2H_6^{2+}(aq) + 2Cl^-(aq)$$

(i) Identify the type of reaction that occurs. *[1]*

(ii) Predict the value of the H–N–H bond angle in $N_2H_6^{2+}$. *[1]*

(iii) Suggest the type of hybridization shown by the nitrogen atoms in $N_2H_6^{2+}$. *[1]*